ESD-TDR-63-242 PM-22 #20

RADAR SYSTEMS AND TECHNIQUES DEPARTMENT MICROWAVE TECHNIQUES SUBDEPARTMENT QPR OCTOBER 1, 1962 – DECEMBER 31, 1962

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MICROWAVE TECHNIQUES SUBDEPARTMENT

Prepared for

DIRECTORATE OF RADAR AND OPTICS
ELECTRONIC SYSTEMS DIVISION
AIR FORCE SYSTEMS COMMAND
UNITED STATES AIR FORCE
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Prepared by

THE MITRE CORPORATION
Bedford, Massachusetts
Contract AF19(628)-2390 Project 750

ABSTRACT

This document reports the progress of the Microwave Techniques Subdepartment from October 1, 1962 to December 31, 1962. The work of the Subdepartment centers about the design, fabrication, and evaluation of microwave techniques and components which have application to long-range radar and communication problems.

CONTENTS

THE MICROWAVE TECHNIQUES SUBDEPARTMENT

INTRODUCTION

The responsiblity for the development of the microwave portion of a line integral refractometer has been undertaken by the Microwave Techniques Subdepartment. This area of responsibility includes the antenna system, coherent two-frequency transmitter, frequency splitter, and the dual mixing system. A varactor doubler will be used for the transmitter and the local oscillator, while the injection for the local oscillator will be made through a sidelobe of the receiving antenna. The desired completion date for the refractometer is 1 July 1963.

PARAMETRIC AMPLIFIER STUDIES

L-Band Parametric Amplifier

The relatively high noise figure (4 to 5 db) of the L-band parametric amplifier, mentioned in PM-22 #17, was the result of shot noise caused by the forward varactor current. One cause of this situation could have been a tuning condition which was met by the high-capacity of the forward bias. To investigate this assumption, an idler rejection filter was inserted in series with the signal tuning adjustment, but this modification did not alleviate the forward bias condition.

Because of the complexity of analyzing a waveguide-to-coaxial cross with a varactor situated in its center, a coaxial parametric amplifier was investigated and designed. This amplifier consists of (1) a coaxial transition from a 50- to a 40-Ω line; (2) a sliding filter that tunes the idler frequency; (3) a varactor in series with the center conductor; (4) a short length of 25-Ω line to tune the varactor at the signal frequency, and (5) a transition from the 25-Ω line to waveguide for admission of pump power. The cutoff frequency of the pump waveguide is chosen such that it reactively terminates the signal and idler frequencies but propagates the pump frequency.

Most of the parts for this amplifier have been fabricated and tested and the final unit will be in operation soon. A theoretical bandwidth analysis has been made for this amplifier, and the resultant equations are being programmed for the 7090 computer.

Cryogenic Cooling

A program has been undertaken to develop a closed cycle cryogenic refrigerator for cooling the L-band parametric amplifier. This refrigerator will achieve an ultimate temperature of $30^{\circ}K$ and will provide approximately 10 watts of refrigeration capacity in the range of 70 to $90^{\circ}K$. The refrigeration is accomplished by a method of cryomatic gas balancing which is analogous to the sterling cycle. Use of this technique results in a simple device with only one moving part — a loosely fitting displacer piston which oscillates approximately fifty times per minute. The technique takes advantage of the high efficiencies obtainable with simple regenerators, and consequently can achieve practical overall efficiencies greater than those possible with expansion engines requiring heat exchangers.

A method of cryomatic gas balancing has been proposed and developed by William E. Gifford of Syracuse University, who will provide the necessary consultation to complete this project. The operation and advantages of the gas balancing method of refrigeration are thoroughly covered in a report on cryogenic refrigeration for electronics being written by Mr. Gifford.

Four refrigeration units are being constructed. The equipment necessary to measure the temperatures in these refrigerators has been completed. This instrumentation consists of chromel-alumel thermocouples as sensing elements driving a calibrated 1000:1 d-c amplifier which, in turn, drives a digital voltmeter. A precision voltage divider was so built that the gain of the d-c amplifier can be set to 1000 ± 0.05 percent. This should result in an overall temperature measurement accuracy of $\pm 2^{\circ}C$ at liquid nitrogen temperatures of $-196^{\circ}C$, provided standard or calibrated thermocouples are used.

Receiver Protection Switch

A strip line diode protection switch, purchased from the Hylectronics Corporation, exhibits the following properties:

Frequency (Mc)	Insertion Loss (db)	Frequency (Mc)	Insertion Loss (db)
1250	0.29	1300	0.23
1260	0.32	1310	0.29
1270	0.25	1320	0.28
1280	0.22	1330	0.32
1290	0.24	1340	0.30
		1350	0.31

The isolation was > 30 db over the entire range, switching speed < 1 μsec, and a power handling capability of 150 watts peak at a 4.0 percent duty cycle.

Solid-State Pump Source

The solid-state pump source mentioned in the previous quarterly progress report was received from Microwave Associates, Inc. Two specifications were not met: spurious responses were not attenuated by at least 30 db, and power output was measured to be 125 mw instead of 150 mw. The unit has been returned to Microwave Associates for correction.

Phase Jitter Tester

Work has continued during this quarter on the L-band phase jitter tester. In an effort to contain the entire system in one cabinet, it was decided to use printed circuit techniques wherever possible. Figure 1 shows the display circuitry on a printed board. Use of this technique increased the cabinet space by approximately one-third. The varactors were to be used for the jitter error multipliers, but this idea has been temporarily shelved in order to obtain more information about their properties. A tube multiplier system has been designed, constructed, and tested. The jitter tester will be completed in the forthcoming quarter.

(a) Front View

(b) Back View

Fig. 1 Display Circuitry on a Printed Board

Electron-Beam Parametric Amplifier

Initial investigation of the theory and performance characteristics of the Zenith Corporation quasi-degenerate L-band electron-beam parametric amplifier was completed. The results will be published soon in a working paper. Future investigations will involve phase shift and jitter, and extreme degenerate operation performance.

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J. H. Phillips

ANTENNA STUDIES

Shielded Horn Experiment

The dynamic range of the receiver was increased to enable the observer to measure backlobes at levels below -60 db. The backlobe level in the transverse plane[1] and with transverse polarization was reported to be lower than -59.3 db. With the increased range, the actual level measured was -61 db.

In the longitudinal plane with transverse polarization, the backlobe level was reported to be lower than -59 db. This measurement also was repeated and shown to be -65 db.

Clay Pit Hill Antenna Range

In the first measurements of the proposed antenna test range, an amplitude variation of 4.5 db was recorded across the aperture of the antenna to be tested. A small ground reflection screen was installed on the hillside between the test antenna and the transmitter. The test was repeated and the variation was reduced to 3.5 db.

Additions will be made to the reflecting screen in increments to produce maximum effect and smallest size.

Monopulse Development

Principal effort during the last quarter was devoted to the development of a feed system suitable for illuminating a cassegrainian subreflector. Models using these designs, which optimize both the sum[2] and difference modes of monopulse operation, have been constructed. The results of the difference mode optimization are summarized in Table I.

In recent months considerable design effort has been devoted to optimizing both the sum and difference modes simultaneously.[3, 4, 5, 6] Several novel methods are being investigated for possible inclusion in the D-22 lab tracker.

Table I

Monopulse Pattern Measurements Difference Mode Optimization

(Frequency - 9250 Mc)

Parameters	Azimuth Plane	Elevation Plane
Σ BW/2 (deg)	2.3	2.0
Σ Sidelobe (db)	11.0	13.2
Δ Sidelobe (db)	12.2	11.9
Δ Null depth (db)	43.0	29.0
Σ Gain (db)	34.98	34.98
Δ Gain (db)	36.58	35.58

As pointed out by Hannon, [7] a four-horn cluster feed will not result in optimum overall monopulse performance, since the sum and difference modes require different feed sizes for optimum performance. Usually a compromise is accepted, and some gain loss and degradation in error sensitivity results. This compromise causes an extremely high spillover ratio which increases sidelobes, backlobes, and antenna noise temperature. Stated another way, the feed sum and difference radiation patterns must be such that the spillover ratios are simultaneously low.

The feed developed by Ricardi [8] simultaneously optimizes the range and angle sensitivities of the system, but at the expense of lower gain and relatively high spillover ratios. In addition, the feed is complex and the comparator network becomes large and costly.

It becomes apparent that in optimizing all three modes in a monopulse system, the use of closely spaced, highly directive feeds is required. But to get high directivity, long end-fire elements, large horns, or lens apertures are required. End-fire elements have restrictions because of defocusing which changes with frequency and angle. If horns are used, the physical aperture size prohibits close spacings.

In Seavey's[9] report, it is pointed out that, by assuming a single collimating element of a monopulse feed and four feeding sources, as the individual sources' beams are tilted further apart, the crossover level decreases, the sum pattern broadens and the difference peaks increase in magnitude while keeping the same location and slope. In other words, there is independent control of the sum mode radiation pattern. This then is the basic idea behind simultaneous monopulse mode optimizing. It is axiomatic that simultaneously optimized feed structures take as many forms as there are particular applications and specification characteristics to be maximized.

Several horns have been fabricated and radiation-pattern tested to obtain design data. The design theory, in practice, is modified by interaction between the sum and difference modes, and it is necessary to equalize the E- and H-plane patterns.[10] The method being used in the lab tracker utilizes compensating fins in the horn aperture for equalization. This method, although acceptable, could cause fringing field effects and deteriorate optimum performance. Another technique is the diagonal horn[11] which has identical E- and H-plane aperture distributions. This is particularly attractive because of the sections of square waveguide which serve as inputs to the horn. With minor modifications, phase shift sections could be inserted to yield circular polarization.

To test this technique, a four-port section is being fabricated. The mandrel for one electroformed diagonal input is shown in Fig. 2. An exploded view of the complete diagonal four-port input is shown in Fig. 3.

During the next quarter it is planned that the dual polarized comparator circuit, currently under electrical test, will be available for pattern testing. Also, delivery of the L-band packaged comparator has been postponed until early in the next quarter because of contractual changes.

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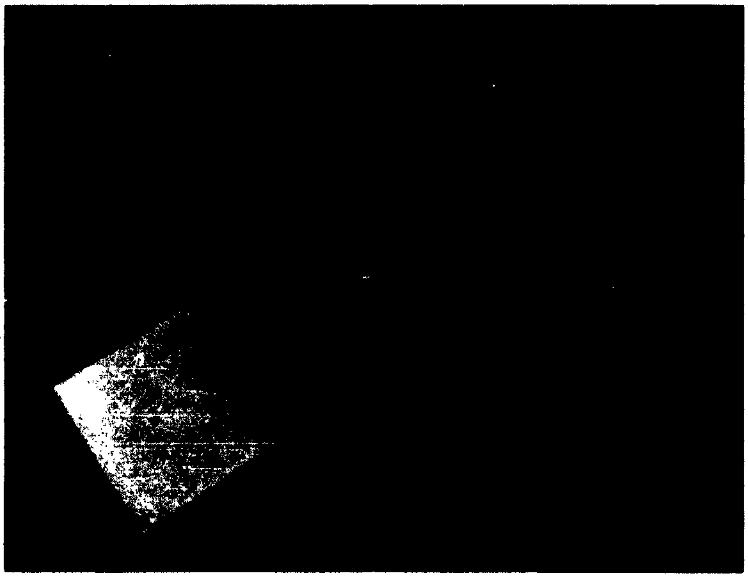

Fig. 2 Mandrel, Rectangular to Diagonally Polarized Input

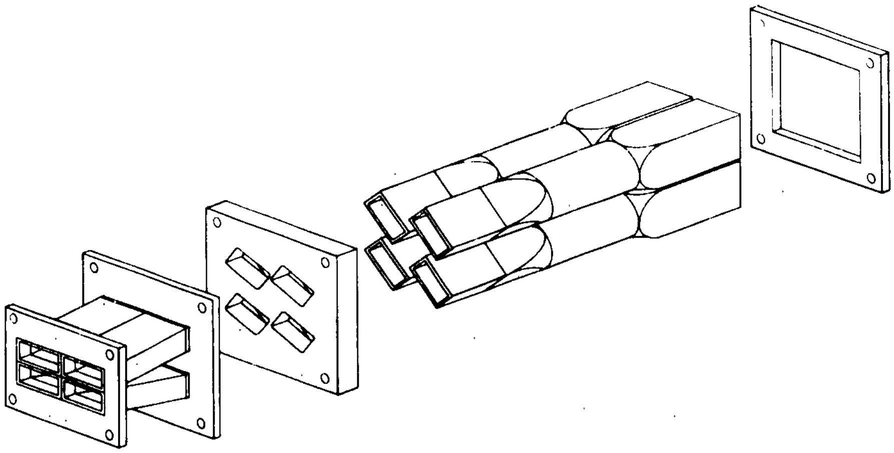

Fig. 3 Transition, Rectangular to Diagonally Polarized Input for Four-Port Monopulse

REFRACTOMETER

During the last quarter a development program was initiated, under the direction of D-20, to build antennas capable of simultaneous dual frequency operation at 16 and 32 Gc. Preliminary investigations of the antenna aspect are summarized in a MITRE memo.[12] Progress to date consists of a survey of development capabilities both in MITRE and industry and, as a result, antenna specifications have been written for parabolic dishes and feeds. These specifications have been sent to MITRE Purchasing who will forward them to outside vendors for price information on the complete antenna package. This data is expected early in the next quarter.

A wideband double-ridge waveguide has been designed and a few aluminum sections fabricated. Four tapered transitions from the double-ridge waveguide to k_u and k_a waveguide also have been electroformed. The calculated cutoff frequencies for the TE_{10} and TE_{20} modes are approximately 11.8 and 33.5 kMc, respectively. This is in close agreement with the measured value of 11.6 kMc for the TE_{10} cutoff frequency. The characteristics impedance, $Z_o{}^{\infty}$, of the ridge waveguide has been calculated. If the discontinuity susceptance of one ridge is neglected, Cohn's Equation 3[13] yields $Z_o{}^{\infty} = 182\ \Omega$, while if the discontinuity susceptance is considered, Chen's Equations 14 and 15[14] yield $Z_o{}^{\infty} \approx 157\ \Omega$. The ridge guide was found to present a free space mismatch VSWR of 1.8:1, which corresponds to a $Z_o{}^{\infty}$ of 193 Ω if the reactive portion of the ridge guide at the interface is neglected. The attenuation of a ridge guide of these dimensions was 1.07 db/meter using Hopfer's[15] attenuation curves at a frequency $f = 3\,f_c$. The measured attenuation value at this frequency was 1.15 db/meter.

High-voltage Microstate multiplier varactors have been received, and the varactor holder for the doubler has been designed (Fig. 4) and is being fabricated.

Because of the proposed local oscillator injection through the receiving antenna, the microwave mixing system must be unbalanced. Two crystal mixers covering the frequency range of 12 to 18 kMc and 26 to 40 kMc have been ordered

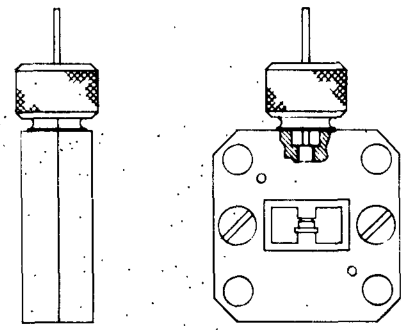

Fig. 4 Ridge Guide Varactor Holder

from Sage Laboratories. In addition, two prototype mixers covering the same frequency range have been received. Upon delivery of the Sage units the prototype mixers will be evaluated and those with the better noise performance selected. Because of the relatively low frequency proposed for this system, diodes especially selected for low 1/f noise have been ordered (Sylvania 1N53C and D4081-R) and should be received soon.

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MICROWAVE LINE LOSSES IN THE BEDFORD RADAR SYSTEM

In order to calculate the antenna system temperature more accurately, it was necessary to measure the actual insertion loss of the microwave transmission lines.

On November 30, 1962, the microwave line insertion loss measurement in both the waveguide and coaxial channels was obtained. The measured values are compared to the calculated values[16] in Table II.

An alternative method, that of measuring the reduction of the VSWR of a short circuit caused by the insertion loss, could not be used because of the

Table II

Insertion Loss and VSWR Measurements

	f (Mc)	Insertion Loss (db)	VSWR
Measured Values			
Waveguide Run (Plane A-A to Plane B-B)*	1280	2.6	1.20
Coaxial Run (Plane A-A to Plane C-C)	1250	3.2	1.45
	1280	3.6	1.65
	1300	4.6	1.55
Calculated Values			
Waveguide Run (Plane A-A to Plane B-B)	1304	2.485	
Coaxial Run (Plane A-A to Plane C-C)	1304	3.94	

*See Fig. 5

relatively high VSWR existing in the line (see Table II). This technique is accurate only for very low VSWRs (1.01 or less) or, essentially, a matched attenuator.

R. D. Gallagher

LASER STUDIES AND TECHNIQUES

Design and Construction

A 1200-joule capacitor-bank containing ten removable 25 microfarad capacitors has been constructed and tested. The bank can be charged to 3000 ± 60 volts with the trigger-charger unit and a d-c digital voltmeter. Each capacitance has been measured to an accuracy of ±2 percent. Either a 0.3- or a 0.6-millihenry choke can be inserted in the discharge path. The d-c resistance of these chokes

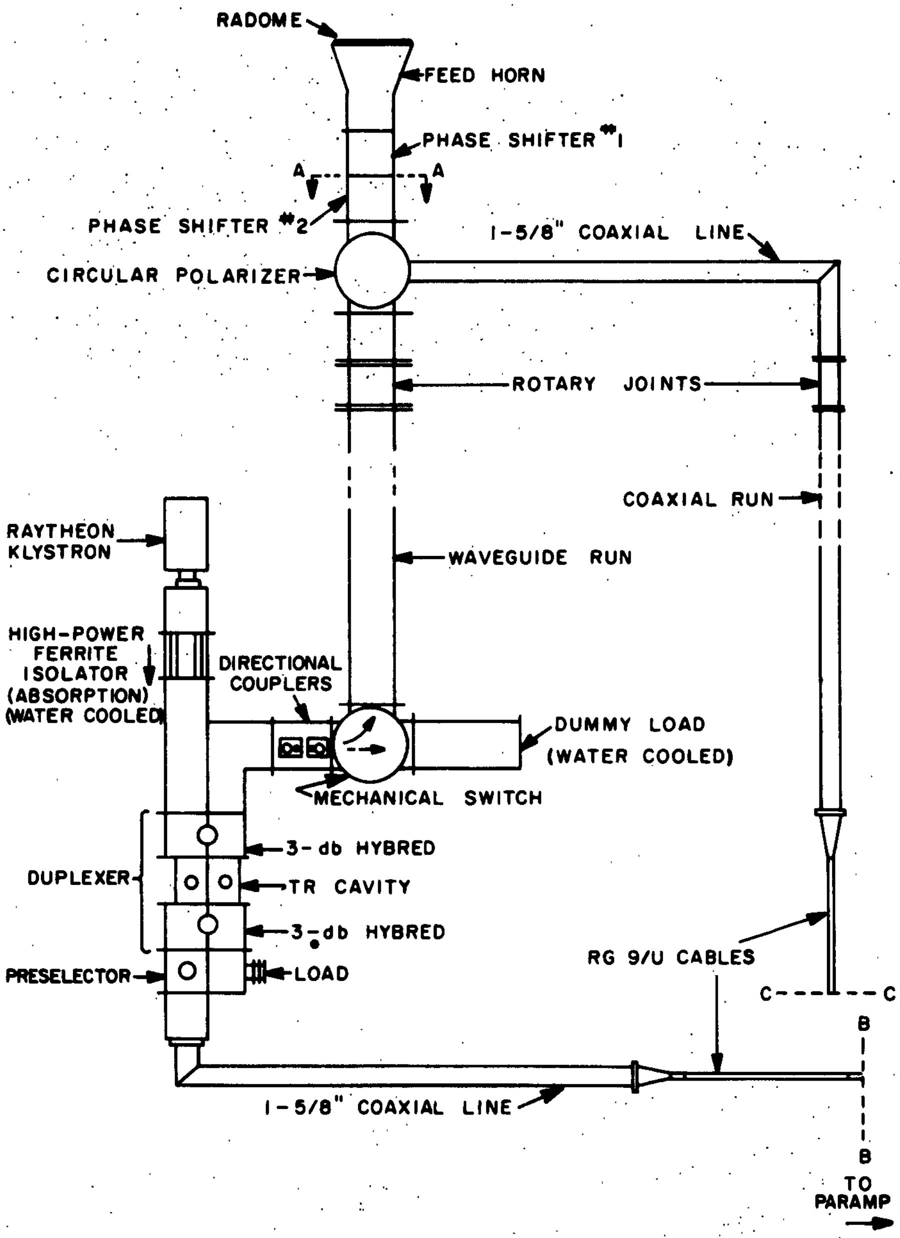


Fig. 5 Microwave System

and their current-carrying leads were measured. The unit is capable of triggering the E. G. & G. Co. type FX 100, FX 38, FX 42, FX-45, and the PEK XE-7 flash tubes.

Two elliptical cavities with adjustable ruby and flash tube holders were constructed and partially tested. Each has a major axis of 5. 000 inches. The minor axes are 4. 976 and 4. 000 inches. Comparison testing of eccentricity and exact focal alignment was performed. Construction of a third elliptical cavity with a fixed 6-inch long ruby and flash tube holder was completed. Experimental results are given in the following paragraphs.

A flash tube of annular cross section, (Fig. 6) has been received from PEK Labs, Inc. The laser rod can be inserted into the hollow cylindrical section along the axis of the tube so that the rod is surrounded by excited xenon gas. The mounting hardware for the testing of this flash tube has been completed. Measurements of input flash lamp power versus laser beam power will be made, using the same ruby rod in all cases, to compare this tube with other pumping methods. This tube will be placed at the center of an optical cavity of circular cross section to reflect escaping pump light back through the tube and into the laser rod.

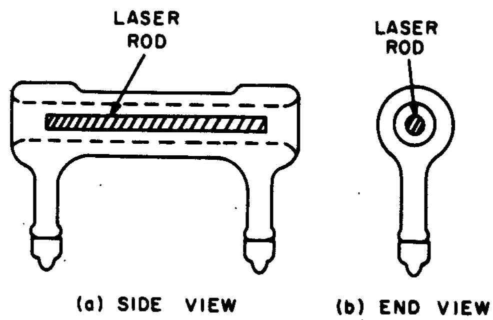
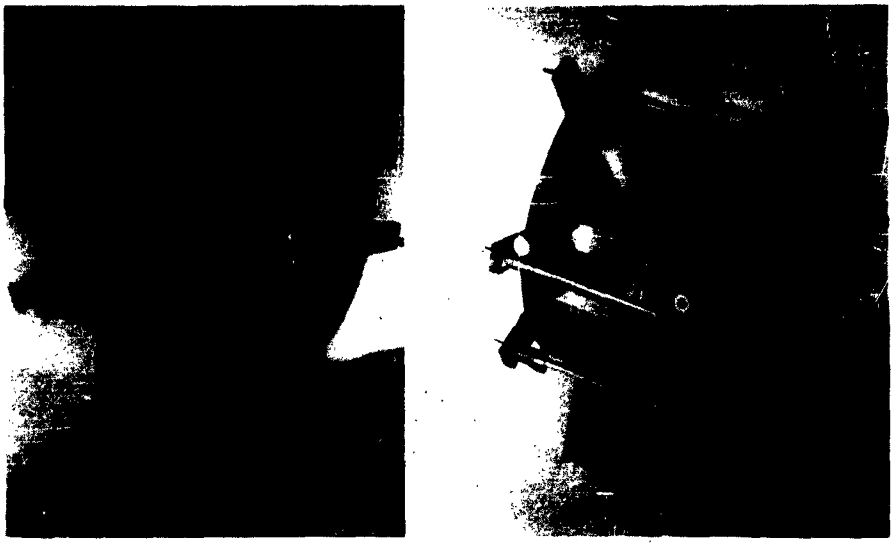


Fig. 6 Annular XE-7 Flash Tube

A multiple flash tube holder was designed and constructed for the investigation of optical coupling. The head (Fig. 7) is capable of holding eight FX-100



(a) Reflecting Cover in Place (b) Interior View

Fig. 7 Multiple Flash Tube Laser Head

flash tubes adjacent to the ruby rod. Each tube is mounted on its own adjustable carriage. A carriage may be positioned at any point along its own 1-inch path which is radially directed from the ruby cylinder. Heating effects and pumping efficiencies will be measured while the number of tubes and their positions are varied.

The variable-delay trigger circuit for oscilloscope synchronization with the flash tube was completed. Since the testing of the phototube detector mount and amplifier is incomplete, a CBS type CP-1 laser detector diode has been used to test the variable delay trigger circuit. A curved photographic film holder for use with a concave grating spectrometer has been constructed.

Experimental Results

The construction and calibration of a carbon cone calorimeter capable of measuring pulsed laser output energy in the 0.002-to-2.00-joule range have been

completed. The final schematic diagram is shown in Fig. 8. Because of the presence of a 60-cps hum at the bridge output, electronic power sources were replaced by battery supplies.

An oscilloscope was used to measure the open-circuit bridge output voltage. The calibration curve for the calorimeter is shown in Fig. 9. During this calibration procedure, the voltage values in the 0.01-to-0.1-joule range varied considerably. The cause of this variation which did not appear on any part of the curve is undetermined. As a result, the voltage values plotted in this region are average values. The accuracy of the calibration data is considered to be ± 15 percent. The capacity of the capacitor bank and the resistance of the current-carrying leads have been accurately measured.

A photograph of superimposed oscilloscope traces obtained from the bridge output of the carbon cone calorimeter is shown in Fig. 10. The lower trace was produced by firing a 2-inch ruby laser into the calorimeter. The upper trace resulted from applying a known amount of electrical energy from a capacitor bank to the same active area of the calorimeter. Comparison shows that the 2-inch ruby laser emits approximately 0.024 joule of energy.

The 6-inch ruby laser became operational during the latter part of this quarter with the 6 X 1/2-inch, 90-degree ruby rod on loan from the Valpey Corporation of Holliston, Massachusetts. The laser head consists of a 4 X 5 elliptical cavity milled of aluminum stock 6 inches long, with the elliptical surface polished to a mirror-like finish. The ruby is held at one of the focus points by a Pyrex vacuum dewar to permit cooling to liquid nitrogen temperatures. The inside diameter of the dewar is slightly larger than the diameter of the ruby and provides clearance for a free flow of cooling gas around the ruby. An E. G. &G. Co. type FX-45 xenon flash tube rated at 2000 joules is located at the other foci of the elliptical cavity. Two views of the laser head are shown in Fig. 11.

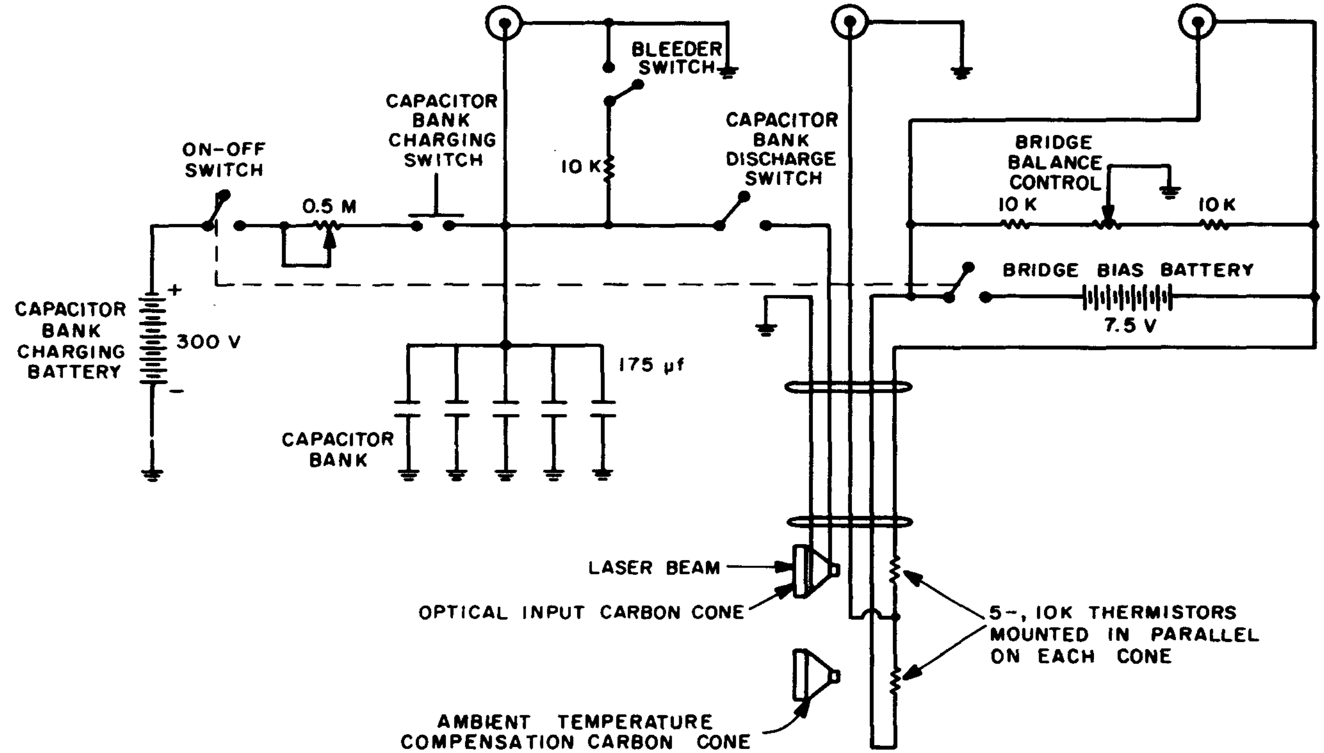


Fig. 8 Schematic of Carbon Cone Calorimeter

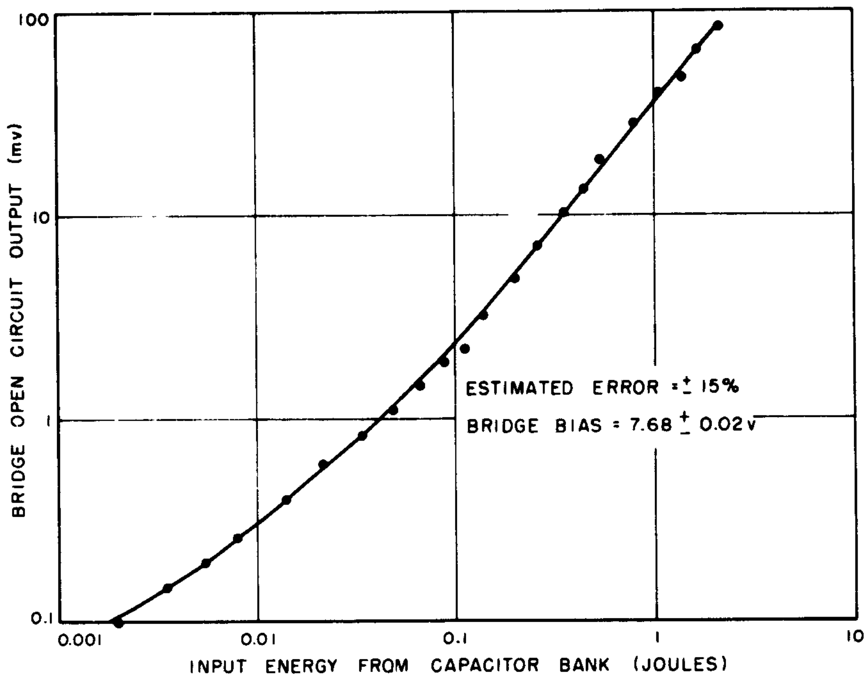


Fig. 9 Calibration Curve of Carbon Cone Calorimeter

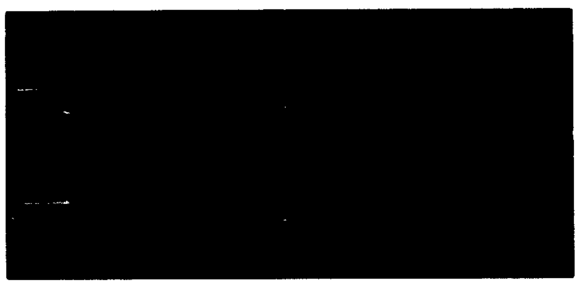
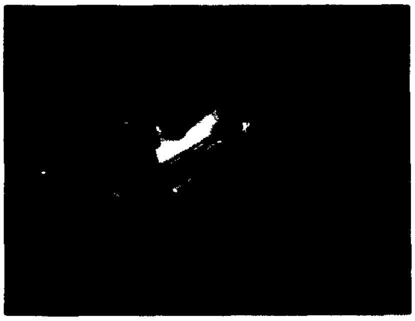


Fig. 10. Energy Output from Two-Inch Ruby Laser

Upper Trace: Calibration Curve for 0.022 Joule from Capacitor Bank

Lower Trace: Output Energy of Two-Inch Ruby Laser (240-Joule Input)

(a) Front View



(b) Back View

Fig. 11 Six-Inch Ruby Laser Head

Some operational difficulties were encountered because of the extremely high heat flash intensity emanating from the xenon flash tube. While the flash duration is of the order of milliseconds, the energy released is so great that extremely high surface temperatures are generated. The intense temperature caused the teflon insulators on the flash tube and trigger leads to vaporize, char, and pit (Figs. 12 and 13). Breakdown occurred across the insulator on the hot negative voltage side of the flash tube. (The other end of the flash tube was at ground potential.) While the dangerous properties involved with the deterioration of teflon at these high temperatures are not known, it was decided to substitute ceramic insulators for these parts. No further difficulties of this type have been encountered since this substitution was made.

A large Sangamo capacitor bank with a 0.3-millihenry choke (E.G.&G. TR-70) has been used to fire the flash tube with various combinations of capacitors. Threshold has been determined for combinations of 2(480 μf), 3(702 μf), and 4(960 μf) capacitors in parallel. Calculations indicate that the flash tube, choke, and capacitor bank combination are probably resonating at a very low

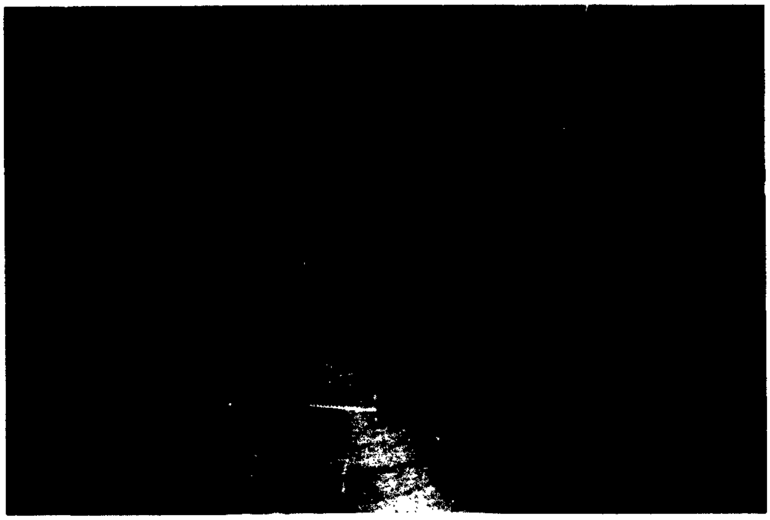


Fig. 12 Results of Arc-Over Damage

Fig. 13 Deterioration of Teflon Insulators Due to Flash Intensity
Interior Views of Six-Inch Ruby Laser Head

frequency. While the flash tube probably is extinguished before the reversed portion of the first cycle occurs, work is continuing to critically damp the network to couple the energy more efficiently. Two laser oscilloscope traces obtained from the bridge output of the 6-inch ruby laser at threshold are shown in Fig. 14. The lower trace shows the power output at 2000 joules input from which the efficiency is calculated to be 0. 065 percent.

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P. M. Ware

Fig. 14 Energy Output from Six-Inch Ruby Laser

Upper Trace: Threshold Output Energy = 0.20 Joule (1100-Joule Input)

Lower Trace: Output Energy = 1.3 Joules (2000-Joule Input)

(Sweep Rate = 5 sec/cm)

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Unclassified Report

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1. Microwave networks
2. Microwave relay systems
3. Microwave equipment

I. Project No. 750
II. AF19(628)-2390
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V. Secondary Report No. PM-22 #20
VI. In DDC collection

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